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TECHNICAL REPORT NO. 13

Contract No.

FAA/BRD-127

CONSPICUITY OF SELECTED SIGNAL LIGHTS AGAINST CITY-LIGHT BACKGROUNDS

PROJECT NO. 110-512R

prepared for

FEDERAL AVIATION AGENCY

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

by

APPLIED PSYCHOLOGY CORPORATION
4113 LEE HIGHWAY
ARLINGTON 7, VIRGINIA

JUNE 1962

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Prepared by

Applied Psychology Corporation
4113 Lee Highway
Arlington 7, Virginia

For

Federal Aviation Agency
Systems Research and Development Service
Washington 25, D. C.

Project No. 110-512R

This report has been prepared by the Applied Psychology Corporation for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. FAA/BRD-127. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the SRDS or the FAA.

June 1962

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Arlington, Virginia
CONSPICUITY OF SELECTED SIGNAL LIGHTS AGAINST CITY-LIGHT BACKGROUNDS, June 1962
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ABSTRACT

Detections of a small signal light against city-light backgrounds were made by experienced pilots during 288 presentations to determine whether detection time was affected by variations in signal characteristics and background, and whether pilot differences occurred.

The experiment yielded evidence that:

1. A red signal light was moderately more detectable than a green one, and the green moderately more so than a white light.

2. Some city backgrounds provided far more difficulty for detection of a flashing signal than others, the primary characteristics of difficult backgrounds apparently being high intensity, concentration of many lights, presence of one or more flashing lights, and wide variety of color.

3. Relative detectabilities among signal colors remained the same regardless of the predominant background color against which they were viewed.

4. A dot-dash flash pattern was significantly more detectable for some subjects and a series of dots more detectable for others.

5. Subjects did not differ significantly in detection time--in spite of using different search patterns.

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SUMMARY OF THE PROJECT

More than 85% of all mid-air collisions have occurred during VFR operations. Since in all likelihood a substantial majority of flights will continue to take place under Visual Flight Rules for some years to come, the Federal Aviation Agency in July 1959 established a program calling for comprehensive research into visual aids for preventing mid-air collisions.

The principal areas being investigated by the contractor, the Applied Psychology Corporation, are paints, exterior light systems, smoke and vapor trails, optical devices, training procedures, and a determination of those items of information needed by pilots for making reliable avoidance-maneuver decisions.

The approach consists of a progression from laboratory work, through field tests, to flight testing. Experimental studies have been conducted to derive those quantitative data regarded as prerequisite to efficient and practical field tests. The field tests have then been designed to assess promising devices and techniques through ground-based observations; as such, they served as economical screenings prior to flight tests.

In-flight evaluations have been reserved for final testing of proposed solutions and for investigating operational problems.

Technical Reports have been, and will be, issued as statements of particular experiments or analytical studies; Summary Reports will be issued as summarizations of all work done in the various broad areas of investigation (e.g., paints, exterior light systems).

The present report is Technical Report No. 13.[1] Other reports, both published and planned for publication, are listed below:

Technical Reports

No. 1 Analysis of the Usefulness of Coded Information in Visual Collision Avoidance

[1] This title replaces the previously listed "Evaluation of the Conspicuity of Aircraft Smoke Trails: B. Air-to-Air Observations" which will not be published.

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No. 2	Comparative Conspicuity of Several Aircraft Exterior Paint Patterns
No. 3	Aircraft Flight-Attitude Information as Indicated by Exterior Paint Patterns
No. 4	Field Study of Threshold Ranges for Aircraft Detection and Color Identification
No. 5	Pilot Judgments of Simulated Collisions and Near Misses: A Comparison of Performance with Uncoded and Two-Tone Coded Models
No. 6, 9, & 14	Effects of Backscattered Light on Target Light Detectability in a Ground Test Environment[1]
No. 7	Outdoor Test Range Evaluation of Aircraft Paint Patterns
No. 8	Flight Simulator Tests of Altitude-Coded Lights
No. 10 & 11	Pilot Judgments of Aircraft Range and Relative Altitude: Ground-to-Air and Air-to-Air Observations
No. 12	Distance Estimation of Frequency-Coded and Uniformly Flashing Lights[2]
No. 15	Altitude Evasion in Visual Collision Avoidance[3]
No. 16	Flight Tests of an Altitude-Coded Aircraft Light[4]

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1 These three Technical Reports have been combined and replace the previously listed reports.

2 This title replaces the previously listed "Evaluation of the Conspicuity of Aircraft Smoke Trails: A. Ground-to-Air Observations" which will not be published.

3 Title changed from that previously listed.

4 Title modified from that previously listed.

Summary Reports

The Role of Paint in Mid-Air Collision Prevention

The Role of Range and Altitude Judgment in Mid-Air Collision Prevention

The Role of Visible Trails in Mid-Air Collision Prevention [1]

The Role of Exterior Lights in Mid-Air Collision Prevention

The Role of Optical Devices in Mid-Air Collision Prevention

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1 Title modified from that previously listed.

TECHNICAL REPORT NO. 13

CONSPICUITY OF SELECTED SIGNAL LIGHTS AGAINST CITY-LIGHT BACKGROUNDS

Introduction

A major problem aircraft pilots often encounter while flying at night over and near cities and other large lighted ground areas is that of detecting and tracking "intruder" aircraft whose exterior lights are superimposed upon the vast complex of lights on the ground. The space over such areas commonly contains a high density of air traffic, and ground lights having great variety of color, intensity, configuration, concentration, and flash pattern often partially conceal from a pilot the flashing lights of aircraft at lower altitudes. In such a situation quick visual differentiation of airborne lights from ground lights is very difficult but frequently critical for avoiding mid-air collisions. The importance of this problem underlines the need to explore the relationships between primary variables and the detectability of a signal light viewed against ground lights, and to specify those variables which appear to be most important to effective operational detection.

Although the problem of detecting other aircraft at night over city lights has been the subject of much conversation among those closely associated with aviation, it has apparently received little systematic investigation. Much study has of course been devoted to basic perceptual processes as related to a light source under various primary conditions of light and of background, but little of this has provided anything directly pertinent to the city-lights situation.

Threshold illumination of a signal light is known to increase as the luminance of the immediate background against which it is seen is increased. Langmuir and Westendorp (1931) have demonstrated, however, that increases in the intensity of steady background lights have little effect on the time required to detect a flashing light signal unless there is a separation of less than three degrees between signal and background. Two investigations of steady and of flashing signal and background lights by Crawford (1959; 1960) have shown that in the special case of a yellow signal, with a background field of many red and green lights (a) greatest conspicuity is provided by a flashing light against a background of steady lights, and (b) least conspicuity is provided by a flashing light against a background of flashing

lights. Crawford found that even a few flashing lights in the background eliminate the advantage of a flashing signal over a steady signal. In another study of flashing lights, Cook and Beazley (1962) found that standard Morse code and signals consisting of dots only possess more promise for the operational situation in terms of response time, learning time, and accuracy than signals constructed from dots and dashes with no pause between units. The differences found in effectiveness among flash patterns thus emphasize flash pattern as a variable whose effect on detectability in the city-lights situation should be investigated further.

Other variables which warrant investigation are color of signal light, its intensity, immediate city-lights background, detection ability of pilots, relative motion of signal light, and atmospheric condition.

Purpose

Purpose of the present experiment was:

(1) to examine the effects of four variables on detectability of a signal light, namely: signal color, signal flash pattern, city-lights background, and observer detection ability; and

(2) to draw inferences from these findings regarding detectability during actual nighttime flight situations over city lights.

Method

Subjects

Four United States Air Force pilots served as subjects. All greatly surpassed the 1000-hour minimum flight experience established as a condition for the experiment, and all were currently on active flight status.

Experimental Design

Subjects were tested separately and received two sets of detection problems, each set involving a different signal flash pattern. Within each pattern set the subject solved 36 problems in which three signal colors and 12 backgrounds were randomly varied. This provided each signal color once against each background. Thus 288 test presentations were provided in the experiment, 72 per subject.

Apparatus

Major elements of apparatus were a signal light fixture, fixture suspension and positioning device, flashing device and control panel, shutter box, oscillograph, and auditory masking system. Figure 1 is a schematic diagram of apparatus layout.

City lights of Tucson, Arizona, provided the background visual field for the experiment. Apparatus was located 400 feet above the city, and city lights were visible at distances of one through 20 miles. A panel aperture of the shutter box permitted each subject to view all city lights lying within a 75-degree segment horizontally, and the full complement of lights vertically. A shutter covered the aperture during periods between test presentations. Electrically actuated release of the shutter by the experimenter began each presentation and provided a time trace deflection. A push button conveniently located near the subject's right hand permitted the subject to indicate detection of the signal light. Pressing the button provided another time trace deflection. A cupped chin rest aided in stabilizing the subject's head position for each presentation, and from this position the subject could specify signal light position as lying within any one of six city sectors by visual reference to markers just above the shutter box aperture.

Test signals originated in a "grain-of-wheat" lamp in a very small fixture supported by fine horizontal wires at a distance of about 25 feet from the subject. Removable filters for the fixture permitted presentations of red, green, or white signals. A neutral filter was used for the white signal. The red and green filters were ground from lenses of aircraft navigation lights. All three filters presented approximately the same intensity of signal light.[1] The diameter of each filter disc was 4.5 mm.

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1 Actually the small size of the fixture and the filter prevented the intensities from being as precisely equal as was desired. The small size of the fixture and low intensities also prevented precise photometric measures of the signal light. However, gross measures made after the experiment revealed that there may have been a difference of about .012 candle between the green and white filters (red falling between these extremes). Even though this difference occurred at low signal intensities, the signals appeared equally intense to observers.

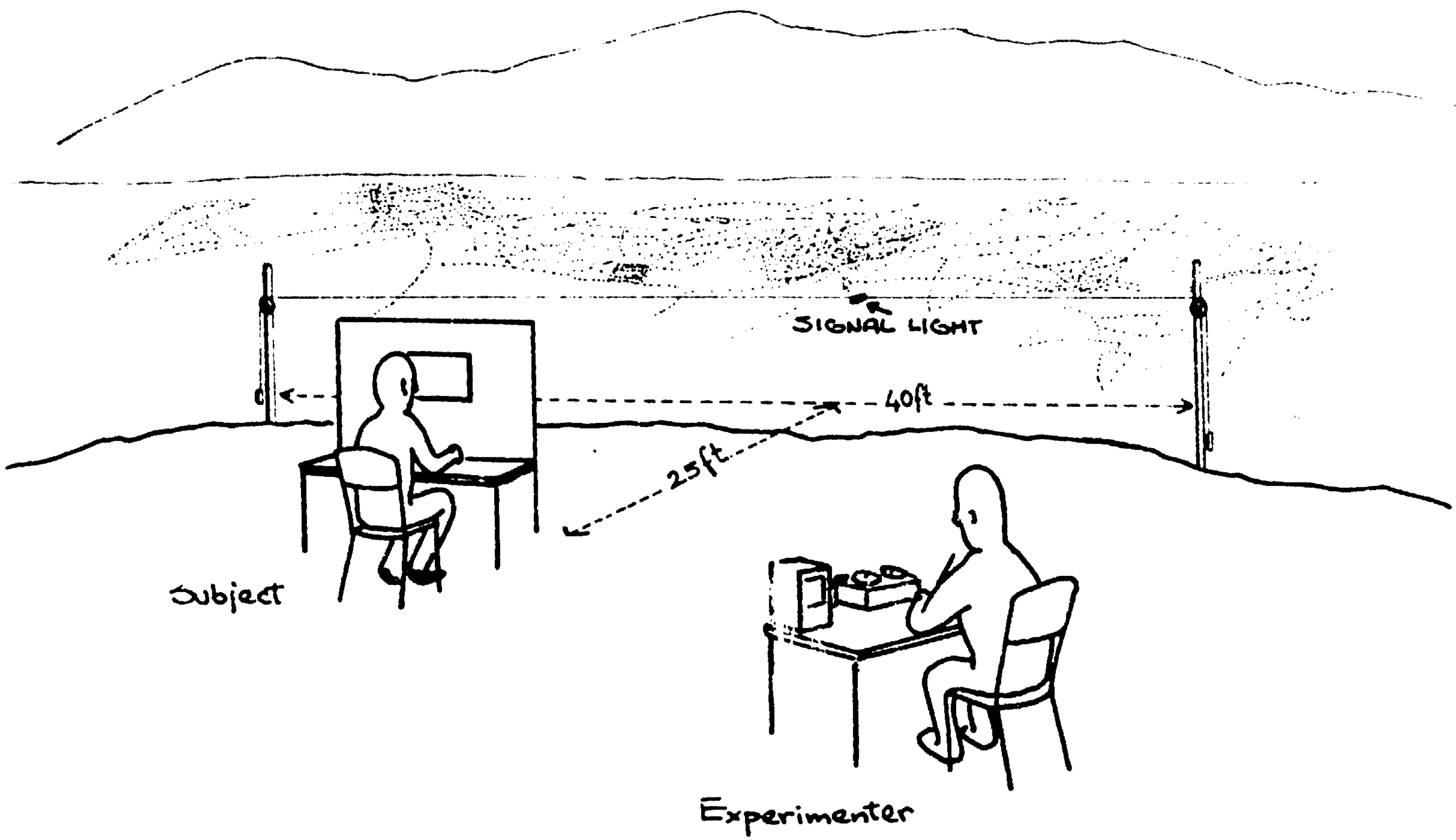


Fig. 1. Diagram of apparatus layout.

The fixture suspension and positioning device consisted of two double-strand wires stretched horizontally between moveable sleeves on 10-foot poles. Matching marks on the poles permitted positioning the sleeves and wires at certain vertical levels, and beads on the wires provided position markers along the horizontal. The location of particular city backgrounds selected for the experiment, as viewed from the shutter box, prescribed the wire levels and bead positions that were used. For any specified presentation during testing, then, desired signal position could be consistently achieved by clipping the fixture over a designated bead and moving the sleeves to their designated level. Neither the supporting and power wires nor the fixtures as such could in any way be detected by a subject under the nighttime test conditions.

A table located near the subject's station at the shutter box served as the experimenter's station and held the flashing device, oscillograph, and a tape recorder. The flashing device consisted of a small box containing two constant speed motors with separate commutator discs that provided dot and dot-dash characteristics to the signal light circuit, as selected.

The front panel of the flashing device provided control switches for selecting flash patterns, releasing the shutter of the shutter box, and for making an independent time trace deflection when no signal detection had occurred within the time limit of a presentation. Also on the panel was a control knob with calibrated dial permitting fine adjustment of signal light intensity.

A single-pen oscillograph made the trace deflection when each presentation began and ended, thus providing a record of detection time. A tape recorder was connected to earphones provided the subject. This served as a masking system between presentations to preclude the subject's obtaining cues to forthcoming signal location from activities in positioning the light fixture.

Backgrounds

Twelve very small areas within the city lights display were specified as the immediate backgrounds for test presentations. Selection of the backgrounds was based on the following general guidelines: (a) backgrounds must represent conditions found frequently in most larger American cities; (b) they must be as diverse as possible, particularly with regard to such characteristics as color, predominant configuration, light intensity, concentration of points of light, and presence of flashing light sources; and (c) they

should change very little in character between 8 and 11 P.M. No attempt was made to specify precisely the spatial limits of "immediate background" nor to specify in detail the characteristics of individual lights which would be immediately adjacent to the signal light position; subjective judgment was used in achieving a position within each configuration that seemed reasonable in terms of the background's predominant characteristics. The 12 backgrounds selected are illustrated and described in Fig. 2.

Procedure

The psychophysical method of limits was used to equate the perceived intensity of the signal light with red filter to the perceived intensity of a particular moderately intense red city light about five miles from the experiment site. The resulting intensity setting was used throughout all practice and test presentations for all subjects.

Each subject was told the purpose of the experiment, examined all features of the apparatus, heard standard procedural instructions read, and participated in practice runs prior to testing. Practice included the subject's use of sector markers on the shutter box to designate for the experimenter the location of a detected signal. For test runs this procedure served as a check that the signal light, rather than another light, had been detected.

Immediately prior to each test presentation the particular signal condition and city-lights background for that presentation was set up; that is, the signal lamp was flashing the specified pattern through the specified filter and was positioned against the specified background. The subject sat facing the closed shutter of the shutter box. By turning off the subject's auditory masking signal the experimenter alerted the subject for the presentation, and the subject placed his head in a fixed position by use of the chin rest. The experimenter then caused the shutter of the shutter box to fall, permitting the subject to view the city lights and to attempt to detect the test signal. Thirty seconds were allowed for detection.

When the subject had detected the test signal and pressed the "detect" button he called out the sector identification, and the experimenter recorded it. The subject then raised the shutter manually to a closed position, where it locked shut automatically, ready for release again during the next presentation, and the experimenter turned on the subject's auditory masking. The subject remained seated at the shutter box and waited for the experimenter to prepare for the next presentation.

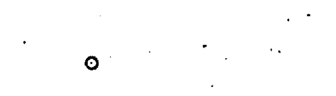
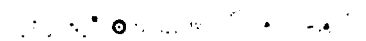
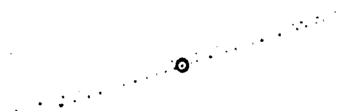
Background Number	Description	Distance From Observer (Miles)	Configuration and Signal Position (circled)
1.	Residential. White street and house lights only. Very faint.	4	
2.	Scattered red signs on business-residential street. A few dim white and green lights. Very faint buff glow from face of large apartment building.	2	
3.	Between three small shopping centers forming corners of a triangle.	3½	
4.	Mercury vapor lighted street. No other colors except a few faint whites near street.	2½	
5.	Heavily lighted downtown area. Shop signs, mercury vapor street lights, traffic signals, auto headlights and taillights, floodlights, etc. Faint glow from faces of larger buildings. Signal was positioned at unlighted base of tall building.	2	

Fig. 2. Description of city-lights backgrounds.

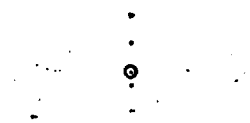
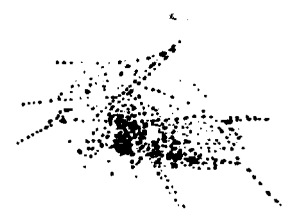
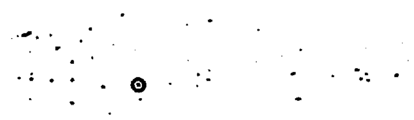
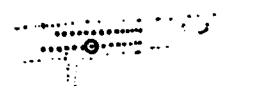
Background Number	Description	Distance From Observer (Miles).	Configuration and Signal Position (circled)
6.	Distant airport runway and associated lights. Faint.	7½	
7.	Large dark areas within the city.	1½	
8.	Many colored signs of extensive business along major thoroughfare.	2½	
9.	Radio-TV tower in sparsely lighted area. Reds of tower predominate.	3	
10.	Same area as background #5. Differs from #5 in that signal was directly over an intense group of lights.	2	
11.	Unstructured arrangement of lights. Predominating white but with reds, greens, blues--all faint.	3½	
12.	Two rows of intense white lights on border of used-car lot.	2	

Fig. 2. Description of city-lights backgrounds. (Continued)

An assistant was responsible for positioning the signal fixture for each presentation and for attaching the prescribed filter cap. A fifteen minute break was provided between the two flash pattern sets.

Results and Conclusions

Detectability has been expressed in terms of detection time. Table 1 summarizes the results of an analysis of variance of detection times obtained in this experiment. As may be noted, statistically significant differences in mean detection times were found for colors, for backgrounds, and for certain interactions between variables.

Data were obtained under ideal conditions of atmosphere and of human attention, and relative motion of signal light to background was absent. These considerations must be borne in mind in relating the results to a real flight environment.

Relation of Color to Detectability

Mean detection times for Aviation Red, Aviation Green, and Aviation White for all test presentations were 4.37, 5.30, and 6.54 seconds respectively. The differences among detection times for these colors are not great, and only the difference between red and white is statistically significant ($t = 2.24$, significant beyond the .05 level).

The fact that no statistical significance was found for any of the interactions between color and other variables separately, indicates that the difference in detectability for red, green, and white is not influenced by the kind of signal flash pattern used, the background against which the signal light is viewed, or the person who does the viewing.

Relation of Flash Pattern to Detectability

For dot and dot-dash flash patterns the mean detection times across all colors, backgrounds, and subjects were 5.05 and 5.15 seconds respectively. The difference in these means is attributable to chance variations, and neither dot nor dot-dash flash pattern can be considered to be more easily detected than the other. The fact that the interaction between flash pattern and subjects is highly significant indicates, however, that although neither pattern is better when all persons are considered together, some observers found one type of flash pattern easier to detect than the other.

Table 1

Summary of Analysis of Variance

Source	Sum of Squares	df	Variance	F
Color (A)	226.09	2	113.04	4.86 *
Bkgd. (B)	2330.53	11	120.96	2.13 *
Pattern (C)	18.25	1	18.25	.10
Subject (D)	175.83	3	58.61	2.52
A x B	520.70	22	23.67	1.02
A x C	23.93	2	11.96	.51
A x D	105.30	6	17.55	.75
B x C	557.95	11	50.72	.91
B x D	1877.82	33	56.90	2.45 **
C x D	521.46	3	173.82	7.47 **
A x B x C	392.24	22	17.83	.77
A x B x D	2228.27	66	33.76	1.45
A x C x D	186.49	6	31.08	1.34
B x C x D	1847.11	33	55.97	2.41 **
A x B x C x D	1534.84	66	23.26	

* Significant at the .05 level.

** Significant at the .01 level.

Relation of City-Lights Background to Detectability

Figure 2 described the characteristics of the 12 city-lights backgrounds against which the signal light was positioned. Table 2 presents the mean detection times for these backgrounds ranked from shortest to longest. As might be expected the shortest detection time was for signals viewed against an unlighted area within the city. The longest was for signals positioned between two parallel strings of very bright white lights that were located on opposite borders of an automobile sales lot.

The particular pairs of background conditions within which there are significant differences, as determined by Duncan's multiple range tests (Edwards, 1960), are indicated in Table 2. Four of the backgrounds, those with the longest detection times, each show significant differences from a majority of the other eight backgrounds. An evaluation of the nature of these four shows they generally share certain common characteristics: a large number of lights densely packed in the immediate background, presence of one or more flashing lights, a high intensity of light (except in one instance), and a variety of colors (except in another, different instance). Of these four backgrounds two were in the middle third of the subjects' visual field, one in the left third, and one in the right third. Two were of a predominantly vertical (in perspective) configuration of lights, one of a horizontal configuration, and one provided three small concentrations of lights defining the corners of an equilateral triangle.

Of the four backgrounds with shortest detection times two common characteristics are: (a) they were all in the left third of the subjects' visual field, and (b) they had low to moderate intensity of light. (Comments on subjects' methods of search may be found in the following section.) It is unlikely that subjects learned to anticipate the appearance of signal lights in certain locations because they were randomly presented. A cursory analysis of a few selected backgrounds for four of the subjects showed that in five of eight cases, detection times tended to be longer for the later presentations against a given background. This further suggests that subjects did not learn to anticipate the locations of the backgrounds.

Interaction between background and subjects is statistically significant. Thus, the difference in detectability of a light against one background and against another background often depends upon the person doing the detecting.

Interactions between background and signal color and between background and flash pattern are not significant.

Table 2

Rank Order of Mean Detection Times and Significant Differences (Duncan's Test) Between Backgrounds[1]

Background Number	Mean Time	7	4	8	9	1	2	11	6	10	3	5	12
7	1.74									*	*	*	*
4	2.80									*	*	*	*
8	3.38									*	*	*	*
9	3.72									*	*	*	*
1	3.87									*	*	*	*
2	4.27									*	*	*	*
11	4.49										*	*	*
6	4.72										*	*	*
10	7.33	*	*	*	*	*	*						*
3	7.75	*	*	*	*	*	*	*	*				*
5	8.56	*	*	*	*	*	*	*	*				*
12	12.18	*	*	*	*	*	*	*	*	*	*	*	

* Significantly different at the .05 level.

1 For a discussion of Duncan's multiple range tests, see Edwards, 1960.

It is therefore interesting to note that whereas some backgrounds were predominantly red, others predominantly green, others entirely white, and still others a mixture of colors, nevertheless the difference in detectability for one color and another color of signal light does not depend on the predominant background color against which they are viewed.

Relation of Subjects to Detectability

The four subjects obtained mean detection times of 4.28, 5.31, 5.54, and 6.48 seconds. Since there is no statistically significant difference in these times, the ability of any one subject to detect the signal light was not significantly better than that of any other subject, under all test conditions as a whole. Consideration of interaction between subjects and flash pattern earlier in this discussion has shown, however, that some individuals displayed more ability to detect dot patterns, others dot-dash patterns. Moreover, consideration of the interaction between subjects and background has indicated some subjects displayed more ability to detect the signal light against certain backgrounds, and other subjects more ability to detect the light against other backgrounds.

Questioning of subjects at the end of test sessions indicated that all four used substantially different general approaches to detecting the signal light and that eye movement patterns differed greatly. This is especially noteworthy in view of the fact subjects did not differ significantly in detection time. All subjects judged the detection problems to be very realistic except for the absence of relative motion between signal and background.

Summary

Pilot observers solved 288 problems in detecting a small signal light against city-light backgrounds to determine whether variations in signal color, signal flash pattern, and immediate background affected detection time, and to determine whether differences in detection time occurred among the pilots. Two sets of problems, for dot and for dot-dash patterns separately, were provided each subject. Each set contained 36 problems in which red, green, and white signal colors and 12 immediate backgrounds were presented in independently randomized orders so that each color appeared once against each background. The signal fixture and positioning wires were undetectable at night.

Results indicated that:

(a) the red signal was moderately more detectable than the green, the green moderately more so than the white;

(b) some immediate backgrounds provided far more difficulty for detecting a flashing signal than others, the primary characteristics of difficult backgrounds apparently being high intensity, presence of one or more flashing lights, concentration of many lights, and variety of color;

(c) relative detectabilities among signal colors remained the same regardless of the predominant background color against which they were viewed;

(d) dot and dot-dash flash patterns did not differ significantly for all subjects together, though dot was significantly more detectable for some subjects individually and dot-dash for others;

(e) subjects did not differ significantly in detection time, in spite of the fact that posttest interviews indicated all four subjects apparently used substantially different search patterns.

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